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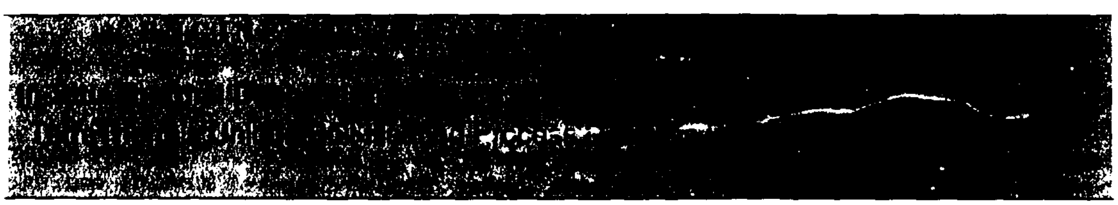

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In-Situ Thermal Desorption

TerraTherm's Unique Soil-Heating Process Destroys PCBs and More

by Jon Hanke

As every environmental engineer knows, technologies that take care of contaminants while they're still in the ground are almost always cheaper than traditional dig-and-haul approaches. But equally axiomatic is notion that every in-situ cleanup technology has major limitations. Some work only in certain soil types and conditions; others handle only a narrow spectrum of wastes. And so far, none has proven commercially viable for PCBs.

The people at TerraTherm Environmental Services Inc. think they can change the way engineers think about in-situ options. The Woodlands, Texas-based company's singular technology combines the thriftiness of soil vapor extraction with the versatility of ex-situ thermal desorption. TerraTherm's in-situ thermal desorption process has already earned some impressive marks in der stration runs at a PCB-con minated site in upstate New York.

If words like "elegant" are appropriate for describing a dirt-cleaning rocess, it could be said that the TerraTherm system has an elegant mplicity. It uses electric heating ds to raise the temperature of contaminated soil past the boiling point any targeted contaminants. Heat is roduced in one of two ways: sur e thermal blankets, which are ef tive to depths of two to three feet, thermal wells, which can go much per. The intense heat destroys e of the volatilized contaminants the ground; those that remain are cuumed" into a flameless thermal oxidizer and carbon bed system for destruction and removal.

TerraTherm's in-situ thermal desorption remediation technology drives off and destroys contaminants by super-heating soil and groundwater with electricity. "Thermal blankets" can treat contaminants near the surface, while "thermal wells" are used for sites with deeper contamination. The technology has been successfully tested at a PCB-contaminated site; other projects are in the works. The system's advantages include its ability to treat a wide range of contaminants in virtually any soil conditions at a cost that compares favorably with traditional ex-situ approaches. TerraTherm hopes to have seven treatment units in the field by the end of the year.

Incorporated last August, TerraTherm still has a lot of proving to do. But as a wholly owned subsidiary of Shell Technology Ventures — Shell Oil Co.'s research commercialization arm — TerraTherm also has the wherewithal to do it. "Obviously, having [Shell's] financial backing is important," says TerraTherm President Jude Rolfes. "It means we can go first-class when we approach a project; we don't need to take any shortcuts."

Origins in the Oil Fields

California may produce some first-rate wines, but the same can't be said about the state's crude oil. "The oil in California tends to be heavy and very viscous," says Jack Hirsch, TerraTherm's vice president of technology. Shell Oil has dominated California's oil fields for nearly a century and Hirsch has worked for the company for 22 years. The company was a pioneer in using thermally enhanced oil production techniques; it developed steam-flooding and other processes to heat underground oil reservoirs in California beginning in the early 1970s. That work gave Shell "an excellent understanding of how heat and hydrocarbons flow through the earth," Hirsch says.

The concept of in-situ thermal desorption is simple — in theory. In practice, it took Shell's extensive knowledge of how heat flows underground to put the theory to work. With decades of experience in manipulating the earth to extract crude oil, Shell was uniquely qualified to execute the "extraction" of volatile and semi-volatile contaminants closer to the surface. "Shell's technical staff is second to none," Rolfes says. "They have an outstanding bunch of scientists and researchers who are really responsible for developing this process."

Shell's observations of how heat, liquids and gases flow underground generated reams of data, the foundation for what Hirsch calls the most accurate simulation models in the industry. "It allows us basically to do

TerraTherm Treatment Systems

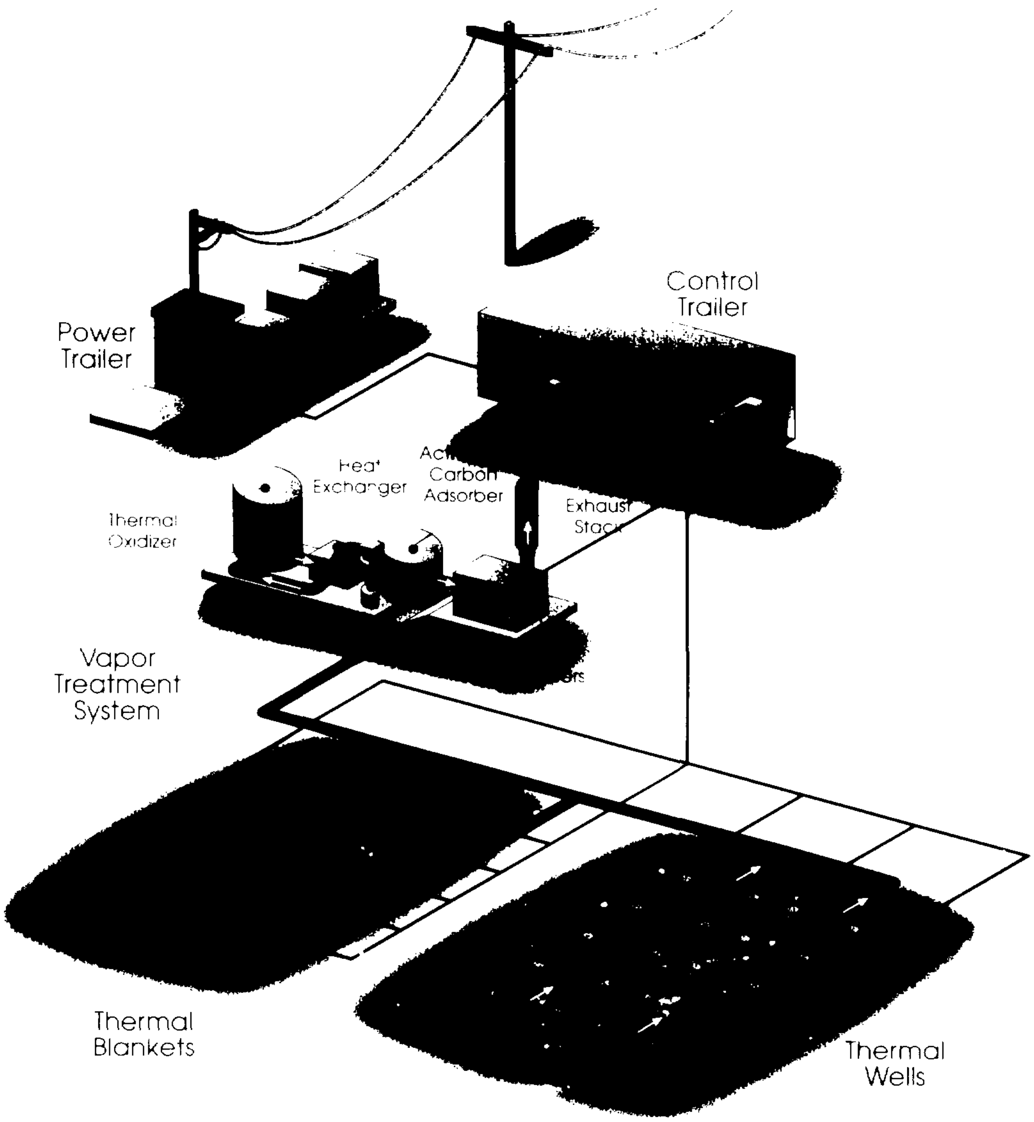

Figure 1

the remediation on the computer and maximize efficiency before putting any metal in the ground," he says.

The TerraTherm System

TerraTherm's in-situ thermal desorption system consists of two components — one set of hardware to transfer heat to the ground and another to capture and destroy the contaminants as they are baked out of the soil. Figure 1 illustrates both manifestations of the TerraTherm system — the version using a thermal blanket to deliver heat and the thermal well design.

Thermal Blankets

As its name suggests, the thermal blanket system is similar to a household electric blanket. A heat-transfer mechanism, composed of a furnace belt interlaced with heating rods, is laid on the ground to be treated. The woven stainless steel furnace belts used by TerraTherm are eight feet wide and identical to those used in traveling furnaces for pottery, steel and other heat-treated products. The belts resemble chain-link fencing, except that the holes between the links are less than an inch across.

The heating rods are 20 feet long and woven through the rungs of the furnace belt at three-inch intervals. Hirsch says the heating rods are made of common resistive heating wire — basically the same type of mineral-insulated nickel-chromium wire found in the coils of an electric range or the rods of a household infra-red heater.

A box-like frame surrounding the heating assembly supports a light-weight stainless-steel vapor barrier, which in turn is topped with roughly 10 inches of vermiculite insulation. The blanket assembly and insulation are covered by an impermeable fiberglass-reinforced silicone-rubber sheet, which is sealed to the ground outside the frame with sand-filled ballast hoses. A suction port is built into each assembly to route off-gases from the space under the blanket to the vapor-treatment system. "We can gang these modules up to 20 blankets at a time," Hirsch says.

Once the assembly is in place, the power is turned on. As the temperature rises, light volatiles near the surface are driven off and captured in the vapor-control system. When the soil reaches 100°C, the temperature plateaus as the moisture in the soil boils off. Along with the water, additional contaminants are driven off through evaporation and steam distillation.

After the blanket heats to its target range — typically 800°C to 1,000°C — thermocouples maintain a steady temperature. In this phase of the operation, contaminants are volatilized at increasing depths as the ground continues to absorb heat from the blankets. As the vapors rise, they pass through successively hotter layers of soil and many are destroyed on the hot surfaces of the soil granules. Any vapors that make it to the surface are routed through the vapor-control system. Additional thermocouples at various ground depths enable operators to closely monitor underground temperatures as the thermal "wave" moves downward through the soil.

When the process is finished, the thermal blankets are turned off and allowed to cool; negative pressure is maintained under the blanket throughout the cool-down period to capture any late-rising gases. After cooling, the blanket assembly can be dismantled and moved to another location.

Thermal Wells

While TerraTherm's thermal blankets can effectively treat soil within two or three feet of the surface, industrial contamination problems are often deeper than that. To heat soils at depths of more than a few feet, TerraTherm does away with the furnace belts and places the heating elements in a series of wells drilled in a grid-like pattern. Each wellbore measures about 4 inches across and is lined with a slotted stainless-steel casing. The heating element is energized until it glows bright red; radiant thermal energy heats the casing, which conducts to the surrounding soil.

During operation, each well is kept under negative pressure, and off-gases are routed through the same vapor-treatment system used with the thermal blankets. Volatilized contaminants are drawn up the wells, which are typically spaced seven to 10 feet apart. To ensure that no contaminants escape through the soil, a vapor barrier caps the area being treated by the wells. "The suction is applied throughout the interval," Hirsch says. "We remediate all the way to the surface with the wells."

According to TerraTherm, the wells can be drilled to depths of several hundred feet; they can also be drilled horizontally to reach contamination beneath roadways, buildings and other structures. Wells can even be bored through concrete floors in buildings. There is no necessary limit to the number of wells that can be operated simultaneously at a site; Hirsch says the only limiting factor is how much power is available. "We have not found power to be a problem," he says. "Most industrial facilities are pretty well fit." If necessary, Hirsch says, a diesel generator can be brought to a site to supply up to four megawatts of additional power.

Vapor Collection, Destruction

The vapor-treatment system is connected to the blanket modules or well caps; a blower maintains negative air pressure across the surface of the treatment area. The system features two main components: a flameless thermal oxidizer and a granular activated carbon adsorber.

TerraTherm's recuperative thermal oxidizer has a capacity of 1,800 scfm. After the packed-ceramic matrix is preheated to about 1,000°C, a propane-air mixture is used to control the temperature of the reaction zone. The oxidizer is rated at 99.99 percent destruction efficiency and has proven even more effective when remediating PCB contamination.

Part of the reason for the unit's impressive numbers, Hirsh says, is the fact that much of the contamination is destroyed before it ever leaves the soil. "A typical surface thermal desorber operates at about 800 degrees [Fahrenheit] or so with about eight minutes of residence time," Hirsch says. "Our well temperature is typically 1,500 to 1,800 degrees, with a residence time that's measured in hours." Based on data from its Houston test site, TerraTherm estimates that its system destroys about 99 percent of the PCBs in situ.

The vapor-treatment system is mounted on a single flatbed trailer; another trailer serves as the system's control room (again, see Figure 1). The surface equipment was designed and built by Shell at its technology-development facilities in Houston. Combined, the equipment on both trailers accounts for nearly half of the $2.0 million to $2.5 million capital investment for each TerraTherm system setup. Most of the equipment is reusable and has a life expectancy of three to five years, Hirsch says.

System Benefits

TerraTherm's biggest selling point is its cost effectiveness when compared with traditional ex-situ technologies for organic contamination, including on-site ex-situ thermal desorbers. To treat soil to a depth of one foot using the thermal blanket approach, the marginal cost is approximately $100 per ton (using a conversion ratio of 1.5 tons per cubic yard). "Our optimal depth is somewhere around 12 inches," Hirsch says. "If it's very shallow contamination, say six inches or so, our costs rise to about $130 per ton." This is because the setup costs are the same; treating twice as many tons (i.e, treating to 12 inches instead of six) just takes a little longer. At contaminant depths of 18 to 24 inches, Hirsch says, marginal costs jump back to around $120 to $130 per ton because it takes much longer to heat to these depths from the surface.

When thermal wells are used, the marginal cost of treatment comes out to about $95 per ton for a typical site. "The actual depth of the contaminant is not a strong driver in the cost of remediation," Hirsch says, because heat can be transferred to the surrounding soil along the entire length of the well shaft, speeding the process. And drilling a well 20 or 30 feet further than you would have otherwise adds little to the cost of the well.

Of course, when all the sampling, permitting, performance testing, analytical work and air monitoring costs are figured in, the total cost of any remediation job is considerably more than the marginal cost of operating the equipment. "The all-in cost for a modest-sized job — 10,000 or 20,000 tons — is around $180 to $200" per ton of treated soil, Hirsch says.

One variable in the price equation is the overall size of the job. "If you have a 100,000-ton job, you're looking at something that approaches $95 a ton in turnkey costs," Hirsch says. "You get enough tons in there, and the front-end costs go away." Another variable is the boiling point of the contaminant being treated. "A heavier molecule like a PCB requires a higher temperature than a light one like benzene," Hirsch says. "That means more electric costs and more time on site."

Even at prices approaching $200 per ton, the TerraTherm process compares favorably with on-site thermal desorption, which typically runs between $200 and $300 per ton when permits, tests and monitoring costs are included.

With ex-situ technologies, Hirsch notes, excavation of the contaminated soil often requires the removal of massive amounts of adjacent clean soil in order to shore up the pit, adding to the cost. "When compared to other technologies, it's very clear that a deep contaminant is tremendously favored by this technology, because the cost of excavation goes up quite a bit with depth," Hirsch says.

Other advantages of the TerraTherm system have to do with the fact that it's an in-situ technology. Remediation can be conducted at an operating facility with minimal disruption — an important economic factor for any industrial client. It also means a reduction in what Hirsch terms the "social costs" of remediation. With the in-situ process, there is no heavy earth-moving machinery, no dump-truck traffic, no billowing dust clouds — and, presumably, fewer complaints from neighboring property owners. "Once we put either the blankets or the wells in place, there's really no more activity, save that the earth is getting hot and the vapors are being destroyed," Hirsch says.

Versatility is another selling point. According to TerraTherm, the process can treat a wide variety of volatile and semi-volatile organic contaminants, including chlorinated solvents, pesticides and petroleum wastes. Hirsch emphasizes that it's one of the few in-situ technologies that's been proven effective at cleaning up PCBs.

TerraTherm is still probing the boundaries of the system's capabilities. One uncharted area is manufactured gas plant sites, which are usually contaminated with coal tars and other heavy, difficult-to-treat organics (see "Manufactured Gas Plants," *EI Digest*, May 1995). Hirsch notes that some of these compounds boil at temperatures of 400°C or higher. TerraTherm is currently testing sample materials from an MGP site to determine whether the system is compatible.

TerraTherm also plans to test the technology's ability to remove and capture mercury and other volatile metals. "We have some good theoretical ideas about what our limits might be, but we'll feel a lot more comfortable after we've finished testing," Hirsch says.

Unlike some other in-situ processes, TerraTherm is not limited to homogeneous or highly permeable soils. "The thermal conductivity of all known soils is very similar," Hirsch says. Generally, the denser the soil, the greater its ability to absorb heat. For example, diatomite — a very porous material common in California — is one of the least heat-conductive soil types, while tightly packed clay is one of the most, but the difference in thermal conductivity between them is only a factor of two. What this means is that any type of soil will conduct heat roughly as well as any other — and, in turn, the TerraTherm process works with almost any soil type.

The TerraTherm system's drying action enables the treatment of wet clays and other fine-grained soil types that ordinarily would inhibit vapor flow. "We dry out the clay," Hirsch explains. "When you take it and completely desiccate it, it has a good ability to transmit gases." This in-situ drying action allows the system to work in soil conditions that would pose problems for surface thermal desorbers. Along the same lines, Hirsch says TerraTherm's process is also effective in areas where buried rocks, debris or other included material would slow down an excavation effort.

Building A Résumé

TerraTherm has two completed in-situ thermal desorption projects under its belt, including a commercial demonstration at the South Glens Falls Drag Strip state Superfund site in New York, conducted in early

Terratherm PCB Cleanup Results

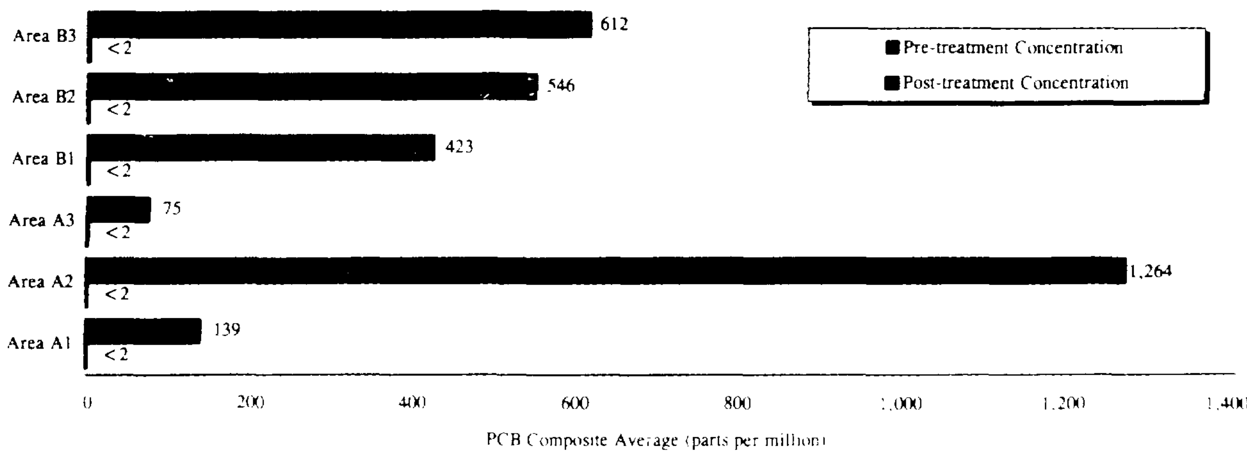

Figure 2

1996. PCB-tainted oil had been used to control dust at the drag strip during the 1960s, leaving PCB residuals in the surface soil. Average PCB concentrations in the 4,800-square-foot demonstration area ranged from 75 to 1,264 parts per million, with a maximum concentration of 5,212 ppm. Most of the PCBs were contained in the first six inches of soil, making this an ideal demonstration site for the new technology.

The Glens Falls demonstration ·oved the thermal blankets' ability to remediate PCBs in situ. In each of the six test areas where the highest PCB concentrations were found, TerraTherm's process was able to reduce concentrations to between 0.03 ppm and 0.8 ppm (see Figure 2). Furthermore, stack-test results from the vapor-control system showed that over 99.99999 percent of the PCBs were effectively destroyed.

The other completed demonstration was a simulation test at the company's research laboratory in Houston. There, a controlled patch of soil was soaked with two surrogate chemicals with high boiling points — methyl salicilate and hexadecane — then treated with the thermal blanket system. TerraTherm plans to publish the results of the simulation soon.

A commercial in-situ desorption project is currently under way at a perchloroethylene-contaminated loading dock area adjacent to an operating industrial facility in Indiana. This project represents the first commercial field application of TerraTherm's thermal wells; some of the treatment wells were drilled right through the loading dock, Hirsch says. Treatment of the 50-by-150-foot area — contaminated to a depth of 20 feet — began in January and was expected to be finished in March.

The Indiana project also represents TerraTherm's first exposure to groundwater. According to Hirsch, groundwater slows the in-situ desorption process because of the time it takes to boil off, but it can actually help the cleaning process because of steam's contaminant-stripping capabilities. For lighter organics, groundwater also acts as a natural barrier to concentrate and contain the contaminants prior to cleanup.

The key to success when groundwater is involved, Hirsch explains, is to control the recharge. If the recharge is naturally fast, some sort of barrier — a slurry wall, sheet pile or array of guard wells — is generally necessary. At the Indiana site, the barrier consists of a trench lined with a slotted PVC pipe and backfilled with gravel. "That's been very effective," Hirsch says.

The Market: PCBs and Beyond

TerraTherm will attempt to capitalize on the system's somewhat unique ability to treat PCBs in its initial marketing efforts, Hirsch says. He notes that PCB-cleanup opportunities are most abundant in the Northeast, where numerous electric railroad lines, utility companies and manufacturing facilities have a legacy of PCB contamination to contend with.

Pending the test results on wastes from manufactured gas plant sites, such sites might also be a good match for the TerraTherm process, Hirsch says. "One project we're contemplating for this summer involves a manufactured gas site in the Northeast," he says. He adds that the social cost advantage of TerraTherm's in-situ process might carry weight in this market area, given MGP sites' proximity to heav-

ily populated areas and their propensity to smell really, really bad.

In terms of marketing thermal wells versus thermal blankets, the company isn't pushing one approach over the other. "We're happy to do either," Rolfes says. "It would be nice to get a balance of about half-and-half, but it's the market that's going to dictate the use of one approach or the other."

TerraTherm, which currently employs 20 people, has assembled two in-situ thermal desorption field units; Rolfes hopes to have a total of seven units in the field by the end of 1997. "We have a full backlog of jobs now," Rolfes says. "We have 11 other sites that we are in active negotiations with to see if we can get a deal closed. We believe that good execution — getting the jobs done properly — is going to be the key."

Both Rolfes and Hirsch are fairly new to the remediation field. Before joining TerraTherm last summer, Rolfes was a power-plant developer and commercial-asset manager for Enron Corp., an international electric utility company based in Houston. Rolfes acknowledges that the site remediation industry is no longer the explosive growth market it once was; he also knows that timing is critical to the success of any startup.

Nevertheless, given the positive demonstration results and the already full backlog of commercial jobs, Rolfes is optimistic about TerraTherm's prospects. He predicts that the company will generate revenues of around $10 million in its first full fiscal year. "I don't think we're really concerned that we didn't hit the high tide of remediation," he says. "This is a unique technology that does a thorough job of cleaning the soil. We think there's enough need to make the whole venture quite successful." ∆

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